

May 2013 Mineral of the Month: Vesuvianite

Our Mineral of the Month is vesuvianite, a chemically complex silicate from a classic locality in Mexico. Our write-up explains its metamorphic origin and occurrence in a massive skarn deposit not far from Mexico's largest iron mine.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: $\text{Ca}_{19}(\text{Al,Mg,Fe})_{13}\text{Si}_{18}\text{O}_{68}(\text{O,OH,F})_{10}$ Basic Calcium Aluminum Magnesium Iron Oxyfluorosilicate (Calcium Aluminum Magnesium Iron Oxyfluorosilicate Hydroxide), often containing copper, beryllium, chromium, manganese, and boron.

Class: Silicates

Subclass: Sorosilicates (Double-Tetrahedral Silicates)

Group: Vesuvianite

Crystal System: Tetragonal

Crystal Habits: Usually as short, prismatic crystals with square cross sections; occasionally long prismatic; also columnar, granular, massive, and compact.

Color: Yellow, yellowish-green, green, amber, and greenish-brown; occasionally reddish-brown, sherry, purple, violet, blue-green, colorless, white, or blue. Often exhibits prominent color zoning.

Luster: Vitreous to resinous

Transparency: Transparent to translucent

Streak: White

Refractive Index: 1.700-1.721

Cleavage: Poor in one direction, indistinct in two others.

Fracture: Subconchoidal, brittle.

Hardness: 6.5

Specific Gravity: 3.3-3.5

Luminescence: None

Distinctive Features and Tests: Translucent, green vesuvianite can be confused with jade, but is harder and more dense than either jadeite [sodium aluminum iron silicate, $\text{Na}(\text{Al,Fe})\text{Si}_2\text{O}_6$] or nephrite (a variety of the actinolite-tremolite series of basic calcium magnesium iron silicates). Vesuvianite is similar to certain color varieties of zircon [zirconium silicate, ZrSiO_4], but unlike zircon, it is not fluorescent. Laboratory analysis is necessary to distinguish vesuvianite from wiluite [basic calcium aluminum magnesium iron titanium oxyborosilicate, $\text{Ca}_{19}(\text{Al,Mg,Fe,Ti})_{13}(\text{B,Al})_5\text{Si}_{18}\text{O}_{68}(\text{O,OH})_{10}$].

Dana Classification Number: 58.2.4.1

NAME: Vesuvianite, pronounced veh-SOO-vee-ahn-ite, is named for its type locality at Mt. Vesuvius in Campania, Italy. The alternative name "idocrase," pronounced EYE-doh-craze refers, to gem forms of vesuvianite and stems from the Greek words *eidos*, meaning "form," and *krasis*, or "mixture," alluding to its crystal forms that share both nesosilicate and sorosilicate

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characteristics. Variety names include massive, green “californite”; compact, blue “cyprine”; yellowish-green “egeran”; yellowish “xanthite”; and yellowish, fluorine-rich “fluorovesuvianite.” Vesuvianite has also been known as “genevite,” “jevreinovite,” “vesuviana,” “volcanic chrysotile,” and “pyramidal garnet.” In European mineralogical literature, vesuvianite appears as *Vesuvian*, *vesuvianita*, and *vesuvianiet*.

COMPOSITION: Vesuvianite contains the elements calcium (Ca), aluminum (Al), magnesium (Mg), iron (Fe), silicon (Si), oxygen (O), hydrogen (H), and fluorine (F). Its molecular weight consists of approximately 27 percent calcium, 8 percent aluminum, 3 percent magnesium, 3 percent iron, 17 percent silicon, 40 percent oxygen, 1 percent hydrogen, and 1 percent fluorine. Vesuvianite is a member of the silicate group, in which silicon and oxygen combine with one or more metals. The basic silicate structure is the silica tetrahedron (SiO_4)⁴⁻, in which four equally spaced oxygen ions (4O^{2-}) surrounding a silicon ion (Si^{4+}) are positioned at the four corners of a tetrahedron (a four-faced polyhedron). Vesuvianite is a double-tetrahedral silicate or sorosilicate, in which silica tetrahedra share one of their oxygen ions (O^{2-}) with adjacent tetrahedra. Vesuvianite exhibits idiochromatic and allochromatic tendencies, with its colors due to both its essential elements and traces of nonessential elements that act as chromophores (color-causing agents). When nearly pure, vesuvianite is colorless or white, but traces of nonessential elements such as copper, beryllium, chromium, and manganese create a range of colors. Varying amounts of the essential element iron also affect color. Browns and yellows are caused by excess iron, blues by copper, violets and purples by manganese, and greens by chromium. Vesuvianite forms primarily through metamorphic processes and often occurs in skarn deposits.

COLLECTING LOCALITIES: Vesuvianite is a widely distributed, uncommon mineral with relatively few collecting sites. The most notable localities are Coahuila, Mexico; Québec, Canada; Rio Grande do Norte, Brazil; and Castrovirreyna Province, Peru. Other localities are in Italy, Austria, Switzerland, Sweden, Russia, Pakistan, Japan, China, Kenya, and Namibia. In the United States, vesuvianite is found in California, Arizona, New Hampshire, Arkansas, Idaho, Washington, Nevada, and Texas.

HISTORY, LORE & USES: Vesuvianite was recognized as a mineral species in 1795. The alternate name “idocrase” was used interchangeably until 1888, when mineralogists formally confirmed the original name “vesuvianite.” Transparent vesuvianite is faceted into collectors’ gems; translucent forms are cut into cabochons for use in jewelry. According to metaphysical practitioners, vesuvianite crystals promote loyalty, cooperation and courage, while helping to dispel negative thoughts, anger, depression, and fear. Vesuvianite has no technological uses.

ABOUT OUR SPECIMENS: Our specimens were collected at Sierra de Cruces (Mountain of Crosses), Sierra Mojada, Coahuila, in north-central Mexico. This region, a remote, arid, and sparsely populated part of the Chihuahuan Desert, is located 125 miles south of Big Bend National Park in Texas. Sierra de Cruces is 25 miles south of the Hercules Mine, Mexico’s largest iron mine, and the small company town of Hercules, which is the region’s only significant population center. Sierra de Cruces is part of a low, minor mountain range that is the geological surface manifestation of a diorite intrusion and a massive skarn formation. Skarns form when magma intrudes limestone and dolomite host rock, and the resulting heat, pressure,

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and circulation of hot, acidic solutions create an unusual array of metamorphic minerals. Collectible metamorphic minerals, including vesuvianite and the garnet-group member grossular, were discovered at Sierra de Cruces in 1947, but not commercially collected until the 1970s.

COMPREHENSIVE WRITE-UP

COMPOSITION

This is the third time we have featured vesuvianite as our Mineral of the Month. Vesuvianite has only two classic collecting localities in the world: the Jeffrey Mine in Québec, Canada; and Sierra de Cruces in Coahuila, Mexico. In 2000 and 2010, our vesuvianite specimens were from Canada's Jeffrey Mine. This time our specimens are from Sierra de Cruces in Coahuila, Mexico. We are pleased that our vesuvianite specimens have always come from classic localities.

As stated by the chemical formula $\text{Ca}_{19}(\text{Al,Mg,Fe})_{13}\text{Si}_{18}\text{O}_{68}(\text{O,OH,F})_{10}$, vesuvianite is a basic calcium aluminum magnesium iron oxyfluorosilicate containing the elements calcium (Ca), aluminum (Al), magnesium (Mg), iron (Fe), silicon (Si), oxygen (O), hydrogen (H), and fluorine (F). Vesuvianite's molecular weight consists of approximately 27 percent calcium, 8 percent aluminum, 3 percent magnesium, 3 percent iron, 17 percent silicon, 40 percent oxygen, 1 percent hydrogen, and 1 percent fluorine. Our write-ups usually state each mineral's precise quantitative chemistry. But vesuvianite is not known to occur in pure form. The frequent cationic exchange between aluminum, magnesium, and iron ions and the frequent anionic exchange between hydroxyl, fluorine, and oxygen ions results in a very variable chemistry. Because even vesuvianite specimens from the same source can have substantially different chemistries, we can provide only a general statement regarding quantitative chemistry.

Understanding vesuvianite's lengthy and complex chemical formula is not difficult when one remembers that all molecules are composed of positively charged cations and negatively charged anions. Molecules achieve stability when their cumulative cationic and anionic electrical charges are equal. In vesuvianite, the compound cation $[\text{Ca}_{19}(\text{Al,Mg,Fe})_{13}]^{\approx 100+}$ has an approximate electrical charge of +100, while the compound anion $[\text{Si}_{18}\text{O}_{68}(\text{O,OH,F})_{10}]^{\approx 100-}$ has an approximate electrical charge of -100. In this formula, the quantitative proportions of the cationic and anionic elements within parentheses and separated by commas are variable. As the cationic electrical charge increases or decreases, the anionic electrical charge varies proportionally to maintain electrical stability.

Vesuvianite is a silicate, the largest and most abundant class of minerals in which silicon and oxygen combine with one or more metals. The silicate structure is based on the silica tetrahedron $(\text{SiO}_4)^{4-}$, which consists of four equally spaced oxygen ions (4O^{2-}) surrounding a silicon ion (Si^{4+}) and positioned at the four corners of a tetrahedron (a four-faced polyhedron). In silicate minerals, silica anions and metal cations link together like polymers (repeating chains) to form seven different structures: framework silicates (tectosilicates); single- and double-chain silicates (inosilicates); ring silicates (cyclosilicates); sheet silicates (phyllosilicates); independent-tetrahedral silicates (nesosilicates); and double-tetrahedral silicates (sorosilicates).

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Vesuvianite is a double-tetrahedral silicate or sorosilicate. Double-tetrahedral silicates form when a silica tetrahedron shares one of its oxygen ions (O^{2-}) with an adjacent tetrahedron. In this arrangement, two silica tetrahedra ($2SiO_4$)⁴⁻ share this single oxygen ion to form the $(Si_2O_7)^{6-}$ radical (a group of atoms that acts as an entity in chemical reactions). The $(Si_2O_7)^{6-}$ radical is the core of the vesuvianite molecule and its crystal lattice. Within this radical, the single, shared oxygen ion is electrically neutral, while the other six oxygen ions carry a -1 charge. These double-tetrahedral $(Si_2O_7)^{6-}$ units are insular, meaning that they are not directly connected. Within the vesuvianite lattice, the tetrahedra are linked together only by mutual ionic bonding to metal ions. The $(Si_{18}O_{68})^{64-}$ radical begins to form when the negatively charged oxygen ions within its double tetrahedra bond ionically to 19 calcium ions and 13 aluminum-magnesium-iron cationic radicals to form a three-dimensional structure. Because this partially completed molecule $[Ca_{19}(Al,Mg,Fe)_{13}Si_{18}O_{68}]^{\sim 40+}$ has a +40 charge and is thus electrically unstable, it attracts and bonds ionically to negatively charged oxygen (O^{2-}), hydroxyl (OH^{1-}), and fluorine (F^{1-}) ions to achieve stability.

The predominant, strong covalent bonding between the shared oxygen ions within its double-tetrahedral units gives vesuvianite a substantial hardness of Mohs 6.5. Omnidirectional bonding throughout the three-dimensional lattice structure produces no pronounced cleavage planes. Because silica tetrahedra completely shield the metal ions, vesuvianite exhibits no metallic properties. Close atomic packing accounts for vesuvianite's moderately high density (specific gravity 3.3-3.5).

Vesuvianite exhibits properties of both allochromatic ("other-colored") minerals and idiochromatic (self-colored) minerals. When nearly pure, vesuvianite is colorless or white, which is typical of allochromatic minerals. Excessive amounts of the essential element iron, however, create yellow and brown colors. Vesuvianite's allochromatic tendencies become evident when traces of such nonessential elements as copper, beryllium, chromium, and manganese impart colors. Blue colors are caused by copper, violet and purple by manganese, and green by chromium.

The Dana mineral-classification number 58.2.4.1 establishes vesuvianite as a sorosilicate with insular (unconnected) silica groups (58). Vesuvianite is then subclassified (2) as an insular sorosilicate with oxygen coordinations of four or greater (in vesuvianite, the oxygen coordination is seven, as seen in its double-tetrahedral $(Si_2O_7)^{6-}$ structure). Finally, vesuvianite is assigned to the vesuvianite group (4) as the first (1) of three members. The other two vesuvianite-group members are:

wiluite [basic calcium aluminum magnesium iron titanium oxyborosilicate,



manganovesuvianite [basic calcium manganese aluminum iron magnesium silicate,



Vesuvianite forms primarily through metamorphic processes. It occurs with grossular [garnet group, calcium aluminum silicate, $Ca_3Al_2(SiO_4)_3$], wollastonite [calcium silicate, $CaSiO_3$], and calcite [calcium carbonate, $CaCO_3$] in fine-grained, silicate metamorphic rocks (hornfels) and in the contact zones (skarns) of metamorphosed limestone (see "About Our Specimens"). It also occurs with chromite [iron chromium oxide, $FeCr_2O_4$] and magnetite [iron oxide, Fe_3O_4] in

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serpentinite of hydrothermal metamorphic rocks; and with wollastonite, andradite [garnet group, calcium iron silicate, $\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$], and diopside [calcium magnesium silicate, $\text{CaMgSi}_2\text{O}_6$] in carbonatites (carbonate-rich igneous rocks).

COLLECTING LOCALITIES

Few vesuvianite localities yield good specimens. Sierra de Cruces, Sierra Mojada, Coahuila, Mexico, and the Jeffrey Mine at Asbestos, Les Sources Regional County Municipality, Québec, Canada, are the only classic localities. Other sources in Québec are the Maple Leaf, Montreal Chrome Pit, Lake Asbestos Mine, and British Canadian Nos. 1 and 2 mines near Thetford Mines in Chaudière-Appalaches Regional County Municipality.

In the United States, vesuvianite occurs in California at Shepherd Canyon in the Crystal Dome district, Inyo County; the Havilan skarn deposit in the Clear Creek district, Kern County; and Happy Camp on Indian Creek, Siskiyou County. “Californite,” the massive, green variety, is collected at the Pulga deposit on the North Fork of the Feather River, Butte County, California. Other sources in the United States are the Blaisdell marble deposit in the Gila Mountains, Yuma County, Arizona; the Warm Springs district in Blaine County and the Wildhorse Mine in the Alto district in Custer County, both in Idaho; the Pipestone Mine at Bald Mountain in Jefferson County, Montana; Rattlesnake Mountain near Wellpinit, Washington; the Indian Queen Mine in the Buena Vista district, Mineral County, Nevada; and the Marble Canyon Mine near Apache Peak in Brewster County and Babyhead Mountain in Llano County, both in Texas. Vesuvianite also occurs in Arkansas at the Kimzey quarries at Magnet Cove, Hot Spring County; in Connecticut at the Hazen Quarry at Haddam, Middlesex County; in Maine at the Sanford vesuvianite locality at Sanford, York County; in New Hampshire at Joppa Hill near Amherst, Hillsborough County; in Pennsylvania at the Williams Quarry in Easton, Northampton County; and in Vermont at the Belvedere quarries at Lowell and Eden, Orleans and Lamoille counties.

Other localities include the Bola do Laje Mine at Currais Novos, Borborema Mineral Province, Rio Grande do Norte, Brazil; and the Flor de Peru I claim at Pampa Blanca, Castrovirreyna District, Castrovirreyna Province, Peru. In Italy, vesuvianite occurs at its type locality at Mt. Vesuvius in Campania, and the Toscopomici Quarry, Pitigliano, Grosseto. Other European sources are the Wollanig marble quarry in the Afritz Mountains near Villach, Carinthia, Austria; the Cerboia Valley, Albo County, Romania; Piz Lunghin in the Bregaglia Valley near Casaccio, Grischun, Switzerland; and the Långban mines at Filipstad and the Jakobsberg Mine at Nordmark, both in Värmland, Sweden. Russian sources include the Lupikko Mine in the Pitkyakanta district, Karelia Republic, Northern Region; and the Yoko-Dovyrensky Massif near Lake Baikal in Irkutskaya Oblast', Eastern-Siberian Region. In Pakistan, specimens are collected in at Alchuri in the Skarov district, Shigar Valley, Balistan, Northern Areas. A notable Japanese locality is Mt. Ohsa at Ohsa-cho, Okayama Prefecture, Chugoku Region, Honshu Island. Gemmy vesuvianite is collected at the Fushan iron deposit, Xingtai County, Xingtai Prefecture, Hebei Province, China. Africa's notable localities include the Kombat Mine at Kombat in the Grootfontein district, Otjozondjupa Region, Namibia; and the Kaiado district in Rift Valley Province, Kenya.

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JEWELRY & DECORATIVE USES

Vesuvianite gems are quite brilliant due to their relatively high refractive index of 1.700-1.721, which approaches that of ruby and sapphire. Vesuvianite's substantial hardness of Mohs 6.5 suits it for most types of jewelry use, with the exception of rings. Nevertheless, vesuvianite has only limited popularity as a gemstone because it lacks a single, distinctive color. Vesuvianite gems are similar in appearance to peridot [forsterite, magnesium silicate, Mg_2SiO_4], smoky quartz [silicon dioxide, SiO_2], certain color varieties of zircon [zirconium silicate, $ZrSiO_4$], and several other gemstones. Transparent vesuvianite in yellow, green, yellowish-green or amber colors is known as "idocrase" in the gem trade and is cut into collector's gems as large as 10 carats. Gems of this size sell for about \$300 and make attractive display pieces; one-carat gems sell for about \$100. Prices of vesuvianite collector gems vary widely, depending upon degree of transparency, absence of prominent inclusions, and minimal color zoning. Vesuvianite gems are not color-enhanced.

A massive, translucent, green vesuvianite variety was discovered in California in 1900. It was publicized by George Frederick Kunz (1856-1928), America's first gemologist, who named it "californite" and compared it to green jade. Californite later became known as "American jade," "California jade," and "vesuvianite jade." Some gemologists believe that vesuvianite would have enjoyed greater acceptance and popularity as a gemstone had Kunz described it as a beautiful stone in its own right and not as a jade simulant. Californite and other translucent, massive forms of vesuvianite are fashioned into cabochons, beads, and free-form pieces.

Vesuvianite is collected for its unusual colors and well-developed crystals, both as individual and composite specimens, the latter often in association with wollastonite [calcium silicate, $CaSiO_3$] and grossular [garnet group, calcium aluminum silicate, $Ca_3Al_2(SiO_4)_3$].

HISTORY & LORE

German mineralogist Abraham Gottlieb Werner (1747-1817) recognized vesuvianite as a mineral species in 1795 after studying crystals within metamorphosed limestone that had been trapped within lava at Mt. Vesuvius in Campania, Italy. Werner named the new mineral "vesuvianite" after the discovery site. Four years later, the prominent and influential French mineralogist and crystallographer Renè Just Haüy (1743-1822) suggested the name "idocrase," from the Greek *eidos*, meaning "form," and *krasis*, or "mixture," because its crystal habits were similar to those of certain minerals that crystallized in other systems. Both names were used interchangeably until 1888, when mineralogists formally confirmed the original name "vesuvianite." Nevertheless, the name "idocrase" has survived and now refers generally to the gem forms of vesuvianite. In 1929, mineralogists used newly developed X-ray diffraction methods to define vesuvianite's atomic structure.

According to modern metaphysical practitioners, vesuvianite dispels negative thoughts and feelings of anger, depression, and fear, while promoting loyalty, cooperation, and courage.

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For more than a century, wiluite, a rare, dark-olive-green gemstone from Siberia, was thought to be a color variety of vesuvianite. But in the 1990s, advanced quantitative analysis techniques chemically distinguished wiluite from vesuvianite. In 1998, mineralogists recognized wiluite [basic calcium aluminum magnesium iron titanium oxyborosilicate, $\text{Ca}_{19}(\text{Al},\text{Mg},\text{Fe},\text{Ti})_{13}(\text{B},\text{Al})_5\text{Si}_{18}\text{O}_{68}(\text{O},\text{OH})_{10}$], as a new mineral species.

THE CLASSIFICATION OF SILICATE MINERALS

As explained in “Composition,” vesuvianite is a member of the silicate class of minerals and is specifically a sorosilicate or double-tetrahedral silicate. Sorosilicates are one of seven different types of silicate structures. The other six are framework silicates (tectosilicates); single- and double-chain silicates (inosilicates); ring silicates (cyclosilicates); sheet silicates (phyllosilicates); and independent-tetrahedral silicates (nesosilicates). A Mineral of the Month Club member recently asked if we could explain the differences between each of these silicate structures. We thank this member for her interest and offer the following explanation.

Most Minerals of the Month that we have featured over the years have been silicates, which is not surprising because silicates are by far the largest of all mineral classes, having more than 2,000 members—nearly half of all the recognized mineral species. As a group, the silicate minerals vary enormously in chemistry and abundance. While some silicates are chemically simple, others are extremely complex; some are abundant, while others are rare. The silicates are numerous because of their ability to form seven different types of lattice structures that are based primarily on the number of oxygen ions that are shared by the silica tetrahedra.

The silicon atom has four electrons in its outer shell. To achieve stability, an atom must have eight electrons in its outer shell. Silicon most readily obtains a stable outer shell by losing its four outer electrons, thereby becoming the silicon ion Si^{4+} . The oxygen atom has six electrons in its outer shell and most easily obtains a stable, outer shell by gaining two electrons, thus becoming the oxygen ion O^{2-} . Positively charged silicon ions Si^{4+} and negatively charged oxygen ions O^{2-} attract each other. In the simplest of the silicates—quartz [silicon dioxide, SiO_2 —one silicon ion bonds with two oxygen ions to form a stable, electrically balanced molecule. The strong bond between them is covalent, meaning that electrons are shared. Silicon ions and oxygen ions can also bond together as the silica tetrahedron $(\text{SiO}_4)^{4-}$, in which each of the four oxygen ions share in the -4 charge. These oxygen ions can then share their excess electron with metals, while silica tetrahedra can share their oxygen ions with adjacent tetrahedra. This results in the wide range of different structures and possible chemical compositions that account for the large number of silicate minerals.

Silicate classification is based on the number of shared oxygen ions per tetrahedron. A tetrahedron can share from zero to all four of its oxygen ions with adjacent tetrahedra. The physical properties and chemical behavior of the resulting silicate minerals depend upon the nature of these sharing arrangements. Now let's consider each of the seven silicate structural subclasses, remembering that silicate tetrahedra can combine with many different metals and can also attach water molecules (H_2O) and bond with hydroxyl ions $(\text{OH})^{-1}$, fluorine and chlorine (halogens, F^{1+} , Cl^{1+}), and free oxygen ions (O^{2-}).

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Double-Tetrahedral Silicates (Sorosilicates): This silicate subclass forms when each tetrahedron shares one oxygen ion with another tetrahedron, resulting in $(\text{Si}_2\text{O}_7)^{6-}$ groups that act as complex, negative ions. Lattice structures are held together by positive ions that balance the tetrahedral charges. Each pair of bonded tetrahedra shares one oxygen ion, but they not bonded to adjacent pairs. Double-tetrahedral silicates are relatively uncommon and, because of the unusual shape of the double tetrahedron, structurally complex. Most double-chain silicates are moderately hard. Examples are hemimorphite [basic hydrous zinc silicate, $\text{Zn}_4\text{Si}_2\text{O}_7(\text{OH})_2 \cdot \text{H}_2\text{O}$] and vesuvianite.

Independent-Tetrahedral Silicates (Nesosilicates): This subclass is based on tetrahedra that share no oxygen ions at all. The name “nesosilicate” stems from the Greek *neso-*, meaning “island,” and alluding to the isolation of the tetrahedra. The remaining charge on each oxygen ion is satisfied by metal ions that bond ionically to hold the structure together. Independent-tetrahedral silicates are moderately hard and form short, blocky, somewhat square crystals. An example of an independent-tetrahedral silicate is zircon [zirconium silicate, ZrSiO_4]. With no shared oxygen ions at all, the lattice is held together only by the ionic bonding between silica tetrahedra and zircon ions. Independent tetrahedral silicates can also be quite complex. An example is the garnet group of calcium iron magnesium manganese aluminum silicates.

Ring Silicates (Cyclosilicates): The word “cyclosilicate” comes from the Greek *kyklos*, meaning “circle,” alluding to a ring-like shape. This subclass consists of silica tetrahedra joined together in ring structures with each tetrahedron sharing two oxygen ions with adjacent tetrahedra. These resulting rings consists of complex groups of $(\text{Si}_3\text{O}_9)^{6-}$ or $(\text{Si}_6\text{O}_{18})^{12-}$ tetrahedral units and are balanced by metal ions with ionic bonding that hold the lattice together. Ring silicates, which are very strong and develop elongated, striated crystals, include beryl [beryllium aluminum silicate, $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$] and the tourmaline minerals (a complex group of basic sodium aluminum borosilicates).

Sheet Silicates (Phyllosilicates): The name “phyllosilicate” is derived from the Greek *phyllon*, meaning “leaf” or “sheet,” and alluding to thin, flat, crystalline shapes. Sheet silicates form when each tetrahedron shares three oxygen ions with adjacent tetrahedra to form large, sheet-like structures that extend indefinitely in two directions. These sheets consists of $(\text{Si}_2\text{O}_5)^{2-}$ or $(\text{Si}_3\text{O}_{10})^{8-}$ units held together in stacks by ionically bonded metal ions. Examples are kaolinite [basic aluminum silicate, $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$] and the various mica-group minerals such as muscovite [basic potassium aluminum silicate, $\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$].

Framework Silicates (Tectosilicates): The word “tectosilicate” stems from the Greek *tektonikos*, meaning “of a builder,” and alluding to the orderly, three-dimensional structure of the crystal lattice. Framework silicates have tetrahedra that share all four oxygen ions with adjacent tetrahedra to create a framework that extends indefinitely in three directions. If silicon ions occupy all the tetrahedral positions, no metal ions are necessary to balance the oxygen ions and the result is quartz [silicon dioxide, SiO_2]. But if aluminum ions Al^{3+} substitute for silicon ions Si^{4+} , the resulting negative charge is balanced by the ionic bonding of various metal ions. Framework silicates, like quartz, tend to be stable, strongly bonded minerals of relatively low

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specific gravity. An example is microcline [feldspar group, potassium aluminum silicate, KAlSi_3O_8].

Single-Chain Inosilicates: Like cyclosilicates, single-chain inosilicates form when each tetrahedron shares two of its oxygen ions to create $(\text{Si}_2\text{O}_6)^{4-}$ tetrahedral groups or multiples thereof. But instead of forming closed rings, the resulting structures occur in aligned, negatively charged chains of indefinite length. The name “inosilicate” comes from the Greek *in-*, meaning “sinew,” and alluding to long, thread-like shapes. The single-chain inosilicates, which include the pyroxene group of rock-forming minerals, have unusual toughness. Examples include diopside [calcium magnesium silicate, $\text{CaMgSi}_2\text{O}_6$] and jadeite [sodium aluminum iron silicate, $\text{Na}(\text{Al,Fe})\text{Si}_2\text{O}_6$].

Double-Chain Inosilicates: The structural unit of the double-chain inosilicates is an infinite, complex chain that consists of two single chains that share oxygen ions between them. Because of the structure of the joined chains, one of the bonding anions must be a hydroxyl ion $(\text{OH})^{1-}$. Hence, all double-chain silicates are basic minerals. Double-chain silicates include the large amphibole group of rock-forming minerals. An example is actinolite [basic calcium magnesium iron silicate, $\text{Ca}_2(\text{Mg,Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2$].

The silica tetrahedron $(\text{SiO}_4)^{4-}$ has more possible bonding arrangements than any other compound ion. Because each of its seven structural groups has many members, the silicates are by far the largest of all mineral classes.

TECHNOLOGICAL USES

Vesuvianite has served as the model for its own laboratory synthesis, but has no other technological uses.

ABOUT OUR SPECIMENS

Our specimens were collected at Sierra de Cruces, Sierra Mojada, Coahuila, Mexico. Coahuila, one of 31 Mexican states, is located in north-central Mexico and is bounded by the United States (Texas) on the north, and the Mexican states of Chihuahua and Durango on the west, Zacatecas on the south, and Nuevo León on the east. Coahuila has a population of 3.2 million. With an area of 57,727 square miles, it is about the size of the American state of Iowa.

Sierra de Cruces (Mountain of Crosses) is 125 miles due south of Big Bend National Park in Texas in the high plateau country of extreme western Coahuila. The regional plateau topography is broken by the foothills of the northern Sierra Madre Oriental, the main mountain range of eastern Mexico. As part of the Chihuahuan Desert, this region is very arid with vegetation largely limited to agave, mesquite, and creosote. Western Coahuila is sparsely populated, with sprawling cattle ranches served only by small, remote villages. The most significant population center of western Coahuila is the small company town of Hercules that serves the Hercules Mine, Mexico's largest iron mine.

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Sierra de Cruces, a crest in the Sierra Mojada range of low mountains, has an elevation of 6,644 feet, placing its summit about 1,500 feet above the surrounding plateau. The Sierra Mojada range is the surface manifestation of a diorite intrusion and a massive, geological skarn. Skarns form when magma intrudes formations of limestone or dolomite rock. Limestone is a sedimentary rock consisting mainly of calcite [calcium carbonate, CaCO_3]; dolomite rock is a sedimentary rock consisting mainly of the mineral dolomite [calcium magnesium carbonate, $\text{CaMg}(\text{CO}_3)_2$]. The heat and pressure associated with magmatic intrusions initially causes contact metamorphism where the magma contacts the host rock. Hot, acidic solutions associated with the magma then circulate through the rocks, reacting with the carbonates in the limestone or dolomite rock to create many new and unusual minerals. The host rocks supply calcium, magnesium, and carbon dioxide, while the magma provides silicon, aluminum, iron, and other elements. Skarns are characterized by such silicate minerals as vesuvianite, wollastonite [calcium silicate, CaSiO_3], diopside [calcium magnesium silicate, $\text{CaMgSi}_2\text{O}_6$], tremolite [basic calcium magnesium silicate, $\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}(\text{OH})_2$], andradite [garnet group, calcium iron silicate, $\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$], and grossular [garnet group, calcium aluminum silicate, $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$]. Many skarns host economic mineral deposits.

The original limestone and dolomite rock at Sierra de Cruces was laid down in mid-Cretaceous time when the region was covered by a shallow sea. In the late Cretaceous Period some 65 million years ago, tectonic stresses uplifted the Sierra Madre Oriental massif. Although the Sierra Mojada itself was not uplifted, subsequent crustal fracturing enabled dioritic magma to rise into the limestone and dolomite rock to create a massive skarn. Erosion later reduced the surface, but the diorite (an iron- and magnesium-rich granitic rock) intrusion and associated skarn formations, both of which consist mainly of durable silicate minerals, resisted erosion to leave the large, weathered intrusion and skarn elevated above the surrounding plateau as today's Sierra Mojada.

The only vehicle access to Sierra de Cruces is a rough dirt road from the town of Hercules, 25 miles to the north on the Coahuila-Chihuahua state line. Hercules and the Hercules iron mine are located geologically at the northwest end of the Sierra Mojada. The volcanic-hosted Hercules iron deposit is thought to have formed through volcanism related to the magmatic event that created Sierra Mojada skarn. The primary ore at Hercules is magnetite [iron oxide, Fe_3O_4]; secondary ores are goethite [basic iron oxide, $\text{FeO}(\text{OH})$] and hematite [iron oxide, Fe_2O_3]. Prospectors discovered the Hercules iron deposit in 1890, but remoteness, inaccessibility, and administrative confusion resulting from the disputed Coahuila-Chihuahua boundary discouraged mining for decades. Development finally began in the 1970s under the ownership and direction of Altos Hornos de Mexico, S.A. de C.V. With no nearby communities, Altos Hornos constructed a company town to provide services for its mine employees. Today, all of the 3,200 adult residents of Hercules work directly or indirectly for the Hercules Mine. The mine consists of two large open pits and newly developed underground workings. The ore is crushed and concentrated at the site, then converted into a slurry and pumped through a 180-mile-long *ferroducto* (pipeline) to the Altos Hornos steel plant at Monclova, Coahuila. The Hercules *ferroducto* is the world's second-longest, slurry-conveyance pipeline.

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Our vesuvianite specimens were collected from outcrops near the base of Sierra de Cruces. Specimen-quality vesuvianite and grossular were discovered at Sierra de Cruces in 1947. But the site's remoteness, long with the poorly developed specimen market that existed at the time, made commercial collecting impractical. Then in 1974, a local rancher discovered outcrops with large crystals of pink-to-red grossular and yellow-brown vesuvianite. These came to the attention of an Arizona-based, commercial collector who encouraged the rancher to stake mineral claims on the site. By then, a graded gravel road had been built to the Hercules Mine, making accessibility to Sierra de Cruces somewhat easier. Since then, quantities of grossular and vesuvianite specimens have been appearing in specimen markets in the United States. Collecting at Sierra de Cruces remains difficult because of the rugged terrain, arid climate, and, as many collectors have reported, large numbers of rattlesnakes, scorpions, and tarantulas.

As you study your specimen, note first the short, prismatic crystals with square cross sections, which is the typical vesuvianite habit. Many of the prismatic and face edges are beveled, which is also typical of vesuvianite and adds to the complexity of crystal form. The color of these crystals is honey-brown, which is the dominant color of vesuvianite from the Sierra de Cruces locality. Under intense light, the crystals will appear transparent to translucent. Intense light will also reveal that the crystals are heavily included and color-zoned, the latter alternating between lighter honey colors and more intense brown colors. The vesuvianite crystals rest in a matrix consisting primarily of wollastonite [calcium silicate, CaSiO_3] and calcite [calcium carbonate, CaCO_3]. The wollastonite is coarsely-grained and off-white-to-gray in color. The calcite is present in crystalline form in both white and blue colors. Under intense light, the blue calcite has a somewhat opalescent appearance. Although blue calcite is generally uncommon, it is frequently seen in specimens from Sierra de Cruces.

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